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6. AUTHOR(S)

D. Proffitt, R.K. Clayton, & J. Ayer

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)Acurex Environmental
4915 Prospectus Drive
Durham, NC 27713Air Quality Specialists
2280 University Drive
Newport Beach, CA 92660**8. PERFORMING ORGANIZATION
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Acurex Environmental was contracted by the U.S. EPA to demonstrate an advanced pollution control cost reduction strategy at a U.S. Marine Corps maintenance facility in Barstow, CA. One booth was modified and two new booths were built and manifolded into a single air pollution control device. This SERDP funded project grew out of previous studies by the EPA and DoD to evaluate and develop economic volatile organic compound (VOC) control technologies for painting facilities. This first application of partitioned recirculating booth in a high volume production environment fulfills a stated SERDP goal of transferring promising design concepts into reliable production applications.

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Demonstration of Spray Booth Recirculation and Partitioning - Phase II

David Proffitt and Russell K. Clayton
Acurex Environmental
4915 Prospectus Drive
Durham, NC 27713

Jacqueline Ayer
Air Quality Specialists
2280 University Drive
Newport Beach, CA 92660

Presented at :
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UNITED STATES ARMY FORCES COMMAND

Presented by:
David Proffitt

Abstract

Acurex Environmental was contracted by the U.S. Environmental Protection Agency (EPA) to demonstrate an advanced pollution control cost reduction strategy at a U.S. Marine Corps maintenance facility in Barstow, California. One booth was modified and two new booths were built and manifolded into a single air pollution control device. This Strategic Environmental Research and Development Program (SERDP) funded project grew out of previous studies by EPA and DoD to evaluate and develop economic volatile organic compound (VOC) control technologies for painting facilities. This first application of a partitioned recirculating booth in a high volume production environment fulfills a stated SERDP goal of transferring promising design concepts into reliable production applications.

At the Barstow facility, partitioned recirculation allowed a reduction in VOC control equipment and operating costs by reducing the exhaust flow rate by approximately 36 percent. Added design features increased the overall reduction to 63 percent. To ensure the safety of the painters, an on-line continuous VOC monitor was developed to compare VOC levels with the published Occupational Health and Safety Administration (OSHA) PELs. If booth concentrations become elevated, the monitoring

device will modify booth operations to dilute the booth. A thorough post-construction testing program confirmed the partition height and fully characterized the painter environment.

Introduction

Painting and coatings operations present a number of environmental problems and economic challenges. VOCs and other hazardous air pollutants (HAPs) found in paint pigments (metals and oxides) and in the volatile carriers used to convey the paints represent either direct or indirect health threats. VOCs are ozone precursors and may be labeled as toxic, and many metals and metallic oxides are identified on toxic compound lists. Driven by the Clean Air Act Amendments of 1990, improvements are being made toward reducing VOCs and HAPs through coatings reformulation, thereby reducing toxic emissions from painting operations. In some cases these changes are insufficient. As a result, end of pipe controls are being mandated in many instances such as aircraft booths and large production facilities. Many facilities now use, or will be required to add, control devices to destroy/capture VOC emissions by thermal, adsorption or other means. Commonly used filtration performs poorly on small particulate, often containing the more toxic compounds such as metals. Control of these compounds is recognized as necessary to prevent long-term environmental build-up of toxic fugitive emissions.

The challenge facing coatings applications is related to the large volumes of air required in spray facilities to remove overspray and create a safe environment for the painter. OSHA requires a minimum velocity of 100 feet per minute (fpm) through a booth section area when using conventional application techniques. Conventional booth design approaches include no provisions for adjusting flow rate; instead they employ a flow rate with clean filters that is sufficiently high to remain above the 100 fpm minimum after the filters are dirtied. As a result, typical booths emit large volumes of air contaminated with dilute concentrations of VOCs and HAPs. Many locations require conditioning this air by applying heating, cooling, and/or humidity control before introduction into the booth. Within seconds after conditioning, the air passes through the booth and is exhausted outside, dumping the energy used to condition this stream. When secondary control is required, VOC control equipment must be sized for the maximum exhaust flow rate. Traditional thermal techniques require heating this large volume to a high temperature (1,400 to 1,500 °F) to destroy the most difficult compounds, resulting in excessive energy use. Energy consumption is also high during product preparation and initial paint cure-out when the booths are often operated under the same conditions as during painting. Additional energy and operational costs are incurred because secondary thermal controls require lengthy start-up times to reach the required destruction temperatures.

It is readily apparent that cost-effective technologies that can reduce the conditioned or treated air volume in painting facilities would be economically and environmentally beneficial.

Background

The proposed technology has evolved since 1988 when EPA and the U.S. Air Force (USAF) began a joint research and development program to control HAPs. The first study, conducted at McClellan Air Force Base (AFB), led to a conclusion that traditional control technologies can be more economically applied to spray booths after modifications to permit recirculation of a portion of the booth air. The concerns about health and safety for personnel in the booths (OSHA regulation 29 CFR 1910.107) were addressed in later studies at Hill AFB¹. These tests demonstrated to the USAF and OSHA that recirculation could be accomplished without exceeding National Fire Protection Association (NFPA) code requirements or OSHA work place permissible exposure limits (PELs) of HAPs. In addition, these tests were designed to validate using Flame Ionization Detector (FID) technology to monitor toxic compound concentrations in the booth and to initiate automatic safety measures to protect booth personnel.

These studies at Hill AFB led to a discovery that added greater value to the concept. It was found that the toxic emissions were distributed across a vertical gradient at the filter bank, with higher concentrations near the floor of the booth. Data suggested that the exiting flow may be separated into emissions-rich and emissions-lean streams that could be controlled and recirculated, respectively. Later studies performed at Travis AFB² verified the viability of a single design combining the benefits of recirculation for exhaust flow reduction and flow partitioning to capture maximum pollutant mass in the discharge stream and minimize the painter's exposure. In late 1993, the EPA's Air and Energy Engineering Research Laboratory (AEERL) (later renamed the Air Pollution Prevention and Control Division), in conjunction with the U.S. Marine Corps (USMC), contracted with Acurex Environmental to demonstrate these technology innovations. The Marine Corps Logistics Base (MCLB) in Barstow, a high production facility that operates year round at 2-3 shifts per day, was selected as the host site for this program. In addition to providing an ideal location for conclusively demonstrating the viability and applicability of the technical innovations, the MCLB intends to maintain the hardware and system modifications, providing the opportunity for a realistic long-term performance evaluation of the design.

The MCLB site was a prime candidate for this demonstration because it houses extensive priming and painting operations for Marine Corps and other DoD vehicle and ground equipment. The three paint booths are located in a single building, the Marine Corps, Multi-Commodity, Maintenance Center (MC3). The coating materials applied in these booths are part of the Marine Corps Chemical Agent Resistant Coating (CARC) system consisting of a wash primer, epoxy primer, and a polyurethane topcoat.

Booth 1 is a large drive-through vehicle booth primarily used for topcoat application to armored personnel vehicles, Humvees, and other Marine equipment. The booth dimensions are approximately 18 feet high, 20 feet wide and 60 feet long. Ventilation air is introduced through an intake plenum formed when the doors are closed

and exits through filters on the back side walls.

Booth 2 is a smaller (10 feet high, 30 feet wide, and 20 feet long) booth with an overhead conveyor designed for painting small vehicle components. The critical parameter in determining partition height was that significant wash primer containing hexavalent chromium was used in this booth. Fresh air is introduced through a perforated plate into the ceiling plenum at the front of the booth. Contaminated air exits through a filter bank covering the entire back wall.

Booth 3 is a similar booth (10 feet high, 22 feet wide, and 10 feet long) designed for painting pallet loaded equipment. As with Booth 2, the CARC wash primer was the primary driver in determining partition height.

Project Description

A primary objective of the EPA/USMC Technology Demonstration control Program was to demonstrate that recirculation/flow partitioning ventilation provides a safe and cost-effective means of controlling pollutant emissions from paint spray booths using military coatings. Secondly, a promising VOC control technology, using the UV/Ozone process, was installed as the air pollution system (APCS) by another contractor. Further enhancements were investigated by The Applied Research Laboratory (ARL) for potential effectiveness gains in this process.

This paper concentrates on the experiences with the design and application of the partitioned recirculation technique, the safety system monitor, and the validation testing.

The program was implemented in two separate phases:

Phase I Baseline Evaluation of Existing Paint Spray Booth Operations

Phase II Partitioned Recirculation System and APCS Design and
Installation

Technology Demonstration Testing (Part of Phase II)

In Phase I, site specific process operating information was collected through extensive source testing and sample analysis to establish the appropriate recirculation rate for each booth. These data were reduced/correlated to project a safe and efficient recirculation rate and partition height for each booth. Conceptual designs were developed for the recirculating/flow partitioning systems to be installed on each booth. Several key issues were addressed including: exhaust filter system requirements for protecting the downstream APCS; fan system and make-up air intake configurations; and flow control and safety system monitors.

Phase II consisted of two separate and parallel design and construction efforts.

One focused on the design and construction of the retrofitted paint booth ventilation system and exterior structures to accommodate recirculation/ flow partitioning. This included the design and installation of two new booths. The second component involved the design and installation of the UV/Ozone APCS under the direction of the USMC program staff.

The goal of Phase II testing was to characterize the performance of the installed systems on each paint booth. This included assessing the health and safety aspects of the recirculation system, establishing the viability of an innovative safety monitoring system, and evaluating the performance of the recirculation booths.

Technical Description

There are several advantages to recirculation ventilation including energy efficiency; cost-effective ventilation system operation; and reduced APCS capital, installation, and operating costs. These advantages are directly proportional to the recirculation rate - the greater the recirculation rate, the greater the energy efficiency and cost effectiveness. However, the recirculation rate is limited by safety requirements relating to PELs and minimum booth ventilation rates as specified by OSHA. Therefore, the optimum system in terms of costs is one that provides the greatest recirculation rate without exceeding applicable OSHA regulations.

In simple recirculation, a portion of the booth exhaust is removed through a bleed-off duct and vented to an emission control device. The remainder of the exhaust passes back into the booth via a recirculation duct into the intake plenum. The recirculated air is mixed with fresh make-up air which is introduced to replace the exhausted air. Hazardous constituent concentrations in a simple recirculation stream are the same as in the exhausted or treated stream, thus limiting the achievable flow reduction to that allowed by the bulk exhaust stream concentration. Therefore, it follows that a preferable scheme would be to concentrate the hazardous constituents in the exhausted portion of the stream.

The partitioned recirculation system takes advantage of a natural physical occurrence in a laminar, cross-flow paint booth, VOC stratification. Because solid and vapor phase constituents tend to remain at or below the level at which they are released into the booth, the most contaminated air from the lower portion of the booth can be directed to the control device. Recirculation air is withdrawn from the upper portion of the booth which has the lowest constituent concentrations. Therefore, the partitioned recirculation strategy safely increases the efficiency and cost effectiveness of paint spray booth ventilation systems to its optimum point.

Safety considerations are of prime importance in the design of such systems. The two safety requirements that impact recirculation/partitioned flow design are codified in the Code of Federal Regulations (CFR) in sections 29 CFR 1920.107 which specifies

minimum required ventilation flow rate for occupied paint spray enclosures, and 29CFR 1910.1000 which governs worker exposure to hazardous constituents. For non-electrostatic paint spray enclosures, such as the high volume, low pressure (HVLP) systems employed at Barstow MCLB, a minimum linear velocity of 100 fpm must be maintained in the vicinity of the worker. To ensure the safety of the painter, the ventilation system was designed to maintain a minimum 100 fpm linear velocity irrespective of the size or configuration of the workpiece being painted.

Worker exposure to excessive levels of hazardous airborne constituents is regulated by three established OSHA limits:

- 1) PELs - 8-hour time weighted average (TWA) concentrations. The PEL is defined as the concentration at which no adverse health effects are expected for most workers exposed to the contaminants for 8 hours per day, 5 days per week.
- 2) Short Term Exposure Limits (STELs) - 15-minute TWA concentrations
- 3) Immediately Dangerous to Life and Health (IDLH) ceiling limits. Under no circumstances are the concentrations in the respirable air to exceed IDLH values.

Because the recirculation rate is the primary contributor to the quality of respirable air, it must be determined based on these OSHA limits. Because the PEL is the lowest exposure limit specified by OSHA and, therefore the most conservative value, it was used to calculate safe recirculation rates for each booth. In cases where the American Conference of Governmental Industrial Hygienists (ACGIH) established worker exposure guidelines, or Threshold Limit Values (TLVs), for hazardous constituents that were lower than the OSHA PELs, the most conservative of the two values was used. In addition, the USMC elected to apply a safety factor of two in these calculations even though the painter's safety is inherently protected by the personal equipment worn by the booth operators during all painting operations.

The partition height calculation was based on several critical parameters including:

- 1) The hazardous constituent concentration profile at the filter face. This provides key stratification information necessary to determine the appropriate partition height. Extensive filter face testing was performed during the Baseline Characterization Study.
- 2) The collection efficiency of the filter system. This is particularly critical for operations that rely on paints that contain inorganic hazardous constituents such as hexavalent chromium or phosphoric acid. For this facility, three-stage high efficiency filters were installed in each paint

booth to maximize particulate collection and hexavalent chromium removal. The partition height calculations assumed a 99-percent filtration efficiency for hexavalent and total chrome.

- 3) Booth volumetric flow rate. This is dictated by the OSHA requirement for 100 fpm velocity through the booth and the booth cross-sectional area.

From these data, a mathematical expression was derived to predict the concentration of hazardous constituents in the recirculation duct as a function of partition height.

$$C_i = \frac{M_i \times X_i}{Q_b \times \left(\frac{a}{H}\right)} \quad \text{Equation (1)}$$

Where

C_i	=	Concentration of compound i in the recirculated stream as it exits the booth downstream of the particulate filtration system.
M_i	=	Mass release rate of compound i
X_i	=	Percent of total mass of compound i located above the partition height
H	=	Booth exhaust face height
Q_b	=	Booth volumetric flow rate
a	=	Partition height

To add an additional degree of safety, the USMC mandated that the partition height be selected to maintain VOC levels below the OSHA limits in the recirculation duct prior to the mixing with fresh make-up air.

One of the primary considerations in applying this technology to a real-world operation was ensuring that the flow rates through the recirculated and exhausted streams could be maintained as the pressure drop across the filter face changed. The tendency of paint overspray to remain in the lower portion of the booth implies that the filter will not be loaded evenly across the entire filter face. Particulate will preferentially deposit on the lower filter face, raising the resistance or pressure drop across the filter in that area. This can cause the contaminated air from the lower section of the booth to migrate up to the less resistant filter area in the recirculation zone. This condition must be avoided to prevent the unsafe rise of hazardous constituent concentrations in the recirculation air.

In the Barstow MCLB project, constant flow rates in the recirculation and exhaust streams are maintained by using variable frequency drive (VFD) fan motors linked to flow rate sensors by process controllers. As the pressure drop across the lower exhaust face rises to the point at which the flow is impacted, the controllers detect the change and signal the VFDs to increase the fan speed to overcome the increased resistance and maintain the set flow.

As previously stated, while the goal of this technology is aimed at cost effectiveness, the overriding technical concern is painter safety. Therefore, a key component in such a system is a monitoring device that will ensure that the concentrations of hazardous VOCs in the mixed recirculation/make-up air remain below the established safe levels. In this facility, Fourier Transform Infrared (FTIR) monitors continually measure the VOC concentrations in the recirculation stream and perform the OSHA summation calculations to assess the quality of recirculated air. After extensive testing and evaluation of several detection systems including flame ionization (FID) and photoionization (PID) detectors, it was determined that FTIR would provide the highest level of system flexibility, accuracy and overall performance. It provides real-time speciated organic concentration data (and, therefore, real-time OSHA compliance status) with significantly reduced calibration gas and instrument maintenance requirements. To ensure the FTIR's suitability for such an application, comparative studies between traditional organic sampling methods (grab samples and continuous FID data) and FTIR measurements were conducted during the Technical Demonstration Testing.

Booth 1 was equipped with a dedicated FTIR monitoring system while Booths 2 and 3 share a second system (Booths 2 and 3 are designed to never operate simultaneously). Each safety monitoring system is programmed with two set points or action levels. If the recirculation stream VOC concentrations exceed the first set point, the paint delivery system is briefly shut down. Should the second action level be reached, dampers in the recirculation duct redirect the stream into the atmosphere. This temporarily converts the ventilation system to single pass operation and instantly reduces the VOC concentrations in the booth.

Results

Phase I baseline data were used to derive the optimal recirculation rate and partition height for each booth, and the resulting volumetric flow exhaust flow rate to the emission control system. Table 1 summarizes the flow rate reductions achieved for each booth. This clearly shows a significant reduction in exhaust flow from each booth through the implementation of partitioned recirculation and application of flow rate control. The total volumetric flow rate from the three booths dropped from 141,800 cfm of uncontrolled exhaust to less than 42,000 cfm of controlled exhaust and was achieved by a combination of management changes (20 percent), flow rate control and enclosing Booth 2 (42 percent), and partitioned recirculation (36 percent).

Table 1. Summary of volumetric flow rate reductions for Barstow Marine Corps Logistics Base paint booths targeted by the Program^a.

<u>Booth</u>	<u>Initial Exhaust Flow Rate (cfm)</u>	<u>Minimum Flow Required for OSHA 100 fpm Face Velocity (cfm)</u>	<u>Final Exhaust Flow Rate Vented to Control Device (cfm)</u>	<u>Overall Flow Reduction Achieved (%)</u>
1	55,000 ^b	34,000	20,210	63
2	59,300 ^b	32,000	21,330	64
3	27,500 ^c	22,000	14,660	47

- ^a Booths 2 and 3 are not operated simultaneously; the highest booth exhaust flow rate to the control device is $20,210 + 21,330 = 41,540$ cfm.
- ^b Average between clean and dirty filter measurements. Original Booth 2 was an open face booth requiring much higher velocities.
- ^c Based on 125 fpm estimated face velocity.

Future Developments

From the knowledge gained through the Barstow project, we believe there are several additional enhancements that could improve the efficiency and effectiveness of painting operations. As previously mentioned, a real-time VOC monitor is a central element to guaranteeing the painter's safe environment and modifying facility operations to prevent unsafe VOC levels. While this instrument was developed to monitor recirculated fumes, it could be used to monitor the exhaust stream and control the booth operations more efficiently. By monitoring the exhaust flow VOC levels, overall flow rates could be reduced during guns-off periods (preparation and paint cure-out). Furthermore, this instrument could be used to trigger secondary controls, such as turning the burner on or off as levels change. While traditional afterburners require long term heat-up, several proven technologies exist that can reach operating temperature rapidly and, coupled with a concentrator/absorber to bridge the small time gaps between paint application and full temperature operation, would offer significant cost savings over current thermal technologies. After painting stops, VOC levels could be monitored to determine when to ramp fans down, decrease secondary control heat input, and when to turn the facility off. No longer would a booth be required to run all night after painters leave a late painting session while the paint cures, leaving the air make-up units running and the energy use soaring. These additional improvements will provide an optimized, integrated approach to painting operations that will provide DoD with sensible, practical solutions to acute environmental and energy problems.

Conclusion

The partitioned recirculation paint spray booth system can address emissions from a significant portion of DoD's aircraft and vehicle service sector, a leading toxic materials usage area according to Air Force Times. Such a solution is important to DoD's adherence to the 1995 National Emissions Standards for Hazardous Air Pollutants for Source Categories: Aerospace Manufacturing and Rework Facilities and existing requirements for VOC emissions in ozone non-attainment areas.

Broad application of advanced split-flow recirculation paint spray booth systems can have a major impact on reducing energy usage and volatiles emissions from DoD facilities. A recent article in the Air Force Times listed aircraft service as the leading toxic material use within DoD. Data indicate that five of the top ten air discharges from 131 DoD installations that triggered Toxic Release Inventory reporting thresholds are typical paint constituents. Many of the ~425 DoD installations have painting facilities. A recent survey tabulated 68 Army spray painting facilities.

Most spray coating facilities can be retrofitted with partitioned recirculation ventilation to reduce the cost of controlling VOC emissions, whether vented to a conventional or advanced control system. Because this technology operates separately from the APCS, it is compatible with all emission control systems. Fiscal analysis indicates that a booth similar to the Barstow installation with a 36-percent recirculation will yield a 25- to 30-percent reduction in the typical total capital and operating cost of \$4.3 million over a ten year lifetime. Because the degree of flow reduction is a function of many parameters, each booth operation must be individually assessed. For example, the flow rate reduction in a large hanger operation exhausting 250,000 cfm in which 2 or 3 paint stations are used, could be 80 percent or higher. Conversely, the flow reduction in a small booth may be as low as 20 percent, but in practically all cases translates into cost savings.

Even in locations which are not required to control the VOC emissions, the application of this technology may provide substantial cost savings by eliminating the heating or cooling load required to condition large volumes of air. This can be a critical concern for facilities located in less temperate zones of the country or in foreign installations.

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